# Nuclear Science Program

## Notre Dame University
### Nuclear Structure Laboratory

## Introduction

The Nuclear Structure Laboratory at Notre Dame University is built around a broad program in low energy experimental nuclear physics. Our main areas of research are **Nuclear Astrophysics**, studies of nuclear reactions with **Radioactive Ion Beams**, **Nuclear Structure**, and **Fundamental Symmetries**. There are three Van de Graaff accelerators at the laboratory: **FN, KN, and JN.** The thrust of the experimental effort with the KN and JN machines is Nuclear Astrophysics. There are also national laboratory (Radiation Laboratory at ND, ORNL, ANL, LBL, NSCL) and industrial relations (Bechtel of Nevada) for testing detectors, materials analysis, and archeological analysis. The Nuclear Structure Laboratory personnel include five teaching and research faculty (**Aprahamian, Garcia, Garg, Kolata, and Wiescher**), four research faculty( **Giesen, Goerres, Kaiser, and Lamm**), staff, three postdoctoral fellows, twelve graduate students, and typically 5-10 undergraduates (5 during the academic year and 10 during summers). We have been an NSF site for the REU program (Research Experience for Undergraduates) since 1986. The last two years, we have expanded to include high-school teachers as well. The existence of our laboratory provides a tremendous educational impact to a broad community of students from national and international facilities. Additionally, we have chosen an area of community outreach to targeted groups of under-represented minorities in the sciences. Special relations have been forged with traditionally Hispanic and historically Black colleges to formulate summer research programs for students/faculty from physics and engineering. Extra efforts are also invested in mentoring undergraduate/graduate female students. The members of the group also play significant leadership roles in large national and international projects.

## Facilities

The KN and FN accelerators are operational while the JN is presently being installed. The FN accelerator has had an upgrade of new acceleration tubes in 1994 and a recent upgrade to a pelletron charging system. The FN accelerator has two types of ion sources available; a **SNICS** and an **HIS**. A new window-less circulating gas target is presently being installed at the KN. We also have capability for bunched beams of 1-2ns width with 100ns intervals. It is possible to bunch up to 40% of the DC beam intensity. Some unique capabilities at Notre Dame include the **Blue-Giant detector** consisting of 32 ion-implanted Si detectors that can cover a large angular range in one of the general purpose scattering chambers, and the **Twinsol** facility of dual superconducting magnetic spectrometer for the production of radioactive ion beams. Twinsol was the first US low energy radioactive ion beam facility. Additionally, there is a moving tape system with a superconducting solenoid for weak interactions studies, an array of Ge-detectors (3-55% Efficiency and 2-Clover type) for $\gamma$-ray spectroscopy measurements, and a state of the art RDM device for lifetime measurements.

# Scientific Highlights

Some of our most significant scientific highlights have been in studies of reactions using radioactive ion beams and in nuclear astrophysics. Below we list some of our most noteworthy recent scientific highlights in these two areas as well as nuclear structure and studies of fundamental symmetries.

The output of the group has been outstanding. In the period from 96-00, the group had **136** publications in refereed journals (exclusive of conference proceedings) where **23** publications were in Phys. Rev. Lett. or Phys. Lett. . Additionally, there were **78 invited talks** presented at national/international conferences. The research facilities at our laboratory are additionally used by scientists from various university and national laboratories as well as a number of foreign countries. We count a user group of 55 in this same period from 14 US facilities (university + national labs), 11 Foreign countries, and 1 industry (Bechtel-Nevada).

## Radioactive Ion Beams

1. Discovery of very strong sub-barrier fusion in the $^{6}He+^{209}Bi$ system. The effective coulomb barrier was found to be reduced by a remarkable 25%. **PRL81, 4580 (1998)**

2. Identification of the doorway state responsible for the huge reduction of the coulomb barrier in the $^{6}He+^{209}Bi$ system. **(PRL 84, 5058 (2000))**

3. First investigation of nuclear and coulomb effects in the sub-barrier dissociation of the proton halo nucleus $^{8}B$. **( PRL 84, 1862(2000))**

4. Second and by far the most comprehensive study of resonances in the $p+^{7}Be$ system. These resonances are crucial to extrapolation of $(p,\gamma)$ cross-section data to solar energies. **(submitted to PRL)**

5. First measurement of the L/K ratio in the electron capture decay of $^{7}Be$. This is the first experiment to use a cryogenic calorimeter to study a nuclear decay process. A resolution of 9eV was achieved when the best theoretical resolution for Si detectors in the energy range of interest is 250 eV. **(to be submitted to PRL)**

## Nuclear Astrophysics

1. The elastic scattering of $^{12}C(\alpha,\alpha)$ was measured in our laboratory. The issue is of great relevance to the existence of life and the $^{12}C/^{16}O$ ratio in our universe. **(submitted to PRL)**

2. Measurements of Nucleosynthesis in AGB stars. This includes identification of the origin of $^{19}F$ and the fate of $^{20}Ne$.

3. Measurements of stellar neutron sources via the $^{13}C(\alpha,\alpha)$ , $^{13}C(\alpha,n)$, $^{14}N(\alpha,\gamma)$, and the $^{22}Ne(\alpha,n)$ reactions. **(Phys. Rev. C 62, 055801 (2000))**

4. We have been developing applications with the KN accelerator including testing of detectors with Bechtel Nevada and the development of analytical techniques for the evaluation of materials and archeological samples.

## Fundamental Symmetries

Studies in fundamental symmetries involve searches for physics beyond the standard model in searches for scalar weak currents.

1. Positron-neutrino correlations in the β decay of $^{32}Ar$ **(PRL 83,1299 (1999))**

2. Measurement of the neutrino spectrum from 8B **(PRL 85,2909(2000))**

## Nuclear Structure

Work in nuclear structure is divided into studies of giant resonances for the investigation of nuclear incompressibility, the study of exotic shapes, and the exploitation of radioactive ion beams for spectroscopy.

1. Studies of inelastic alpha scattering in a number of nuclei to extract simultaneously the Giant Monopole Resonance and the Isoscalar Giant Dipole Resonance. The results will solve the observed differences in the nuclear incompressibility factors derived from the GMR and ISGDR resonances. **(PRL 79, 609 (1998))**

2. The structure of the N=Z rp-process waiting point nucleus, $^{80}Zr$. **(PRL 84, 2104(2000))**

3. Successful use of the $^{6}He$ radioactive ion beam to allow a γ-ray spectroscopy measurement following a heavy-ion fusion evaporation reaction.

4. Observation of anti-magnetic rotation in nuclei.

5. Discovery of the remarkable additivity of incremental alignments in superdeformed bands. **(PRL80, 1845 (1998))**

## Resources

Our **human resources** add up to 5 teaching/research faculty, 4 research faculty, 3 postdoctoral fellows, approximately 12 graduate students, 5-10 undergraduate students, 1 Technician, and 0.75 of an administrative assistant. We typically graduate 3 Ph.D. s /year. During the most recent academic year, 8 Ph.D.s were granted..

Our financial resources include operational funding from NSF and support from the University of Notre Dame for significant upgrades to the accelerators and the purchase of capital equipment. A detailed budget is given below. Operation costs for the accelerators are approximately $400,000/year. Also, we benefit from the fact that Notre Dame does not charge graduate student tuition and we do receive some support on graduate student stipends. Additionally, the department of Physics runs a machine shop that we have primary access to at a nominal charge.

**Budget:**

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| NSF (99-02) | 1,092,865/yr | FN accelerator grant |
| NSF (98-01) | 97,500/yr | KN accelerator grant |
| Int-NSF (99-01) | 9,200/yr | Germany-US collaboration |
| Int-NSF (00-03) | 18,775/yr | Japan-US collaboration |
| Total | 1,218,340/yr | |
| University of Notre Dame | 300,000/yr | $1.4 Million in 96-01 |

## Future Initiatives

Our future plans encompass new initiatives in radioactive ion beams, nuclear astrophysics, fundamental symmtries, and nuclear structure. We give a brief list below separated by accelerator.

**FN accelerator**

1. The development of Twinsol as a momentum separator to study explosive stellar hydrogen and helium burning.

2. Exploitation of our radioactive ion beams for spectroscopy measurements using our array of Ge detectors. This includes the development of new particle-gamma detection capabilities.

3. The development of a new rabbit system for the study of the ($\beta\nu$) correlations in $^{8}$B $\beta$ decay in searching for evidence of G-parity violation resulting from **u** and d quark mass differences.

**KN accelerator**

1. This low energy, high beam current accelerator is an integral part of the JINA (Joint Institute of Nuclear Astrophysics) collaboration including Notre Dame, Michigan State Univ., U. Chicago, and Argonne National Laboratory.

2. Development of inverse kinematics techniques along with the installation of an ECR source at the terminal for high intensity, low energy heavy ion beams and a recirculating gas-target system.

3. Measurements of nuclear reaction processes in stages of late stellar evolution including H/He induced processes in stellar shell burning and heavy ion reactions in the pre-supernova phase.

4. Nuclear reactions in the supernovae shock fronts.

## FY2001 Budget

Is this in a fact a budget level which will allow our facility to operate in a lean, competitive, and cost effective manner in the years to come?

We feel that we are extremely lean and competitive. We have had little or no capitalization support from NSF in the last ten years. We are presently very cost effective. We feel that we cannot operate at FY2001 budgets and remain competitive. We feel that a **minimum of 30% increase in our capitalization funding** could help us do that. We have been particularly successful in recruiting graduate students in the past. We feel that we will not be able to do this effectively into the future as our facility and the equipment in it shows its age. The brightest and most talented students are interested in seeing and working with the latest and greatest that technology and the field have to offer!